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SPATIOTEMPORAL ASSESSMENT OF VEGETATION INDICES AND LAND COVER FOR ERBIL CITY AND ITS SURROUNDING USING MODIS IMAGERIES

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Abstract

The rate of global urbanization is exponentially increasing and reducing areas of natural vegetation. Remote sensing can determine spatiotemporal changes in vegetation and urban land cover. The aim of this work is to assess spatiotemporal variations of two vegetation indices (VI), the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), in addition land cover in and around Erbil city area between the years 2000 and 2015. MODIS satellite imagery and GIS techniques were used to determine the impact of urbanization on the surrounding quasi-natural vegetation cover. Annual mean vegetation indices were used to determine the presence of a spatiotemporal trend, including a visual interpretation of time-series MODIS VI imagery. Dynamics of vegetation gain or loss were also evaluated through the study of land cover type changes, to determine the impact of increasing urbanization on the surrounding areas of the city. Monthly rainfall, humidity and temperature changes over the 15-year-period were also considered to enhance the understanding of vegetation change dynamics. There was no evidence of correlation between any climate variable compared to the vegetation indices. Based on NDVI and EVI MODIS imagery the spatial distribution of urban areas in Erbil and the bare around it has expanded. Consequently, the vegetation area has been cleared and replaced over the past 15 years by urban growth.

Keywords: MODIS, remote sensing, vegetation index, NDIV, EVI, land cover, time series

INTRODUCTION

The rate of urbanization is increasing throughout the world. According to recent United Nations estimations, the majority of the world's population is living in urban areas and the overall proportion is expected to reach 65% in the middle of the 21th century (United Nations, 2014). However according to the Word Bank (2015) the urban population in Iraq was already 69.5% in 2015.

A gradual increase in the percentage of build-up land results in a reduction of the vegetated areas. Urbanization alters environmental conditions such as climate, biodiversity, quality of water and air that has a substantial impact on human comfort and health. The impacts may become pronounced when they interact on a global scale. Therefore a better understanding of the effect of urbanization is required to support greener sustainable development and climate change strategies (Imhoff et al., 2010). Possible solutions include the creation of green spaces, that are irrigated and fertilized, which are found to considerably reduce the negative consequences associated with transformation into urban environment (Gregg et al., 2003). Remote sensing of urban expansion and vegetation clearing provides information on the spatial and temporal patterns of urban development and its impacts to the environment.

MODIS sensor is able to provide information necessary for monitoring ecosystem dynamics at adequate spatiotemporal resolution using vegetation indices such as EVI and the NDVI. VIs are spectral transformations of two or more bands designed to enhance the properties of vegetation to allow reliable spatial and temporal intercomparisons to photosynthetic health and canopy structural changes. NDVI is chlorophyll sensitive, while EVI is more responsive to canopy structural variations including leaf area index (LAI), canopy type and architecture. The VIs complements each other and improves upon the detection of vegetation changes and the extraction of canopy biophysical parameters (Huete et al., 2002). NDVI was found to be highly sensitive to the vegetation presence as well as its density and dynamics (Zhang et al. 2006). For this reason, the MODIS NDVI can be employed in the quantification of green biomass and vegetation cover. A recent study in China by Li et al. (2010) found that MODIS NDVI was highly correlation with the field verification data of vegetation cover and had obvious advantages for predicting natural vegetation coverage than EVI within their study area.

MODIS VIs are sensitive to multi-temporal vegetative biophysical and canopy changes. Both NDVI and EVI have a good dynamic range and sensitivity for monitoring and assessing spatial and temporal variations in vegetation amount and condition. NDVI generally has a higher range of values over semiarid sites, and the opposite for more humid forested sites with a lower range (Huete et al., 2002). With the support of satellite imagery time-series data it became possible for researchers to obtain phenological information at various spatial and temporal intervals. Looking at publications in the area, it should be stated that the first use of satellite data in the identification of key phenological parameters using NDVI was described in publications by Tucker and Myneni (Tucker et al., 2001; Myneni et al., 2007).

However, there is a range of recent studies in developed and developing countries, focused on the application of Moderate Resolution Imaging Spectroradiometer (MODIS) to model trends in vegetation patterns. Mertes et al. (2015) demonstrated a methodology over East Asia to monitor urban land expansion at continental to global scales using MODIS data, including a multi-temporal composite change detection approach based on MODIS 250 m annual maximum EVI. The study explained that EVI data improved the classification results and is capable of distinguishing between landscape changes in urban environment. A publication by Yuan and Bauer (2007) demonstrated a strong correlation between percent impervious surface and land surface, covering twin cities of Minnesota. Lunetta et al. (2006) preferred MODIS Normalized Difference Variation Index (NDVI) for a time series for southern Virginia with the available MODIS quality indicators. Colditz et al. (2006) demonstrated the effects of different quality levels of MODIS NDVI of evergreen broadleaved forest and savanna in western Africa. It was found that low quality analysis or very lenient settings resulted in a significant decrease in NDVI during the wet season. Therefore, not accurately representing the phenology of evergreen broadleaved forest. A recent study in southern Brazil using MODIS leaf area index has highlighted the merit of the MODIS quality indicators such as NDVI and EVI (Rizzi et al., 2006).

The main driving factors of vegetation growth are precipitation and temperature (Bonan, 2002). Water availability, often directly related to precipitation and its variability, is the driving factor for most semi-arid regions. Several studies have been conducted on the response time between precipitation and phenological activity using satellite-based vegetation indices (Nicholson et al., 1990; Los et al., 2006; Camberlin et al., 2007). Vegetation growth patterns and their connection with climate are studied by vegetation phenology (Schwarts, 2013). Land surface phenology (LSP) is focused on seasonal features of spatiotemporal variation and LSP is also one of the main ecosystem change indicators (Suepa et al., 2016). With the aid of remote sensing imagery information, it has become possible to establish spatiotemporal phenological changes, which enabled phenological monitoring at global, regional and local scales (Zhang et al., 2005).

The goal of this work is to assess spatiotemporal variations of vegetation indices (EVI and NDVI) in Erbil and its environment between 2000 and 2015, using MODIS satellite data and GIS methods, to determine the impact of urbanization on the spatial distribution and temporal dynamic of urban and surrounding natural and agricultural vegetation cover. This is conducted by evaluating biannual mean vegetation indices captured in March and December to determine spatiotemporal processes. Climate data including rainfall, humidity and temperature is also considered between 2000 and 2015, to enhance the understanding of vegetation change dynamics. Correlation analysis is conducted between each climate variable compared to both vegetation indices. Dynamics of vegetation gain or loss will be evaluated through the study of land cover type changes.

STUDY AREA

The study area for this research is the city of Erbil and its surroundings, which is the capital of Iraqi Kurdistan Region (Fig. 1). Situated in the north-east part of Iraq and lies between longitudes 43° 51' 20", 44° 12' 28" and latitudes 36° 05' 58", 36° 15' 54" covering an area around 580 km^{2}. The total numbers of Iraq Kurdistan residents is approx. 4.8 million people., the area is presented by fertile plains, uphill and mountainous lands (United Nations Development Program, 2016). The Zagros Mountains (3600 m above the sea level) form the main landscape of the north part of the Kurdistan area. Looking at the distribution of vegetation it should be indicated that agricultural areas form approximately 34% of Iraqi Kurdistan while the dominating land cover of this region is

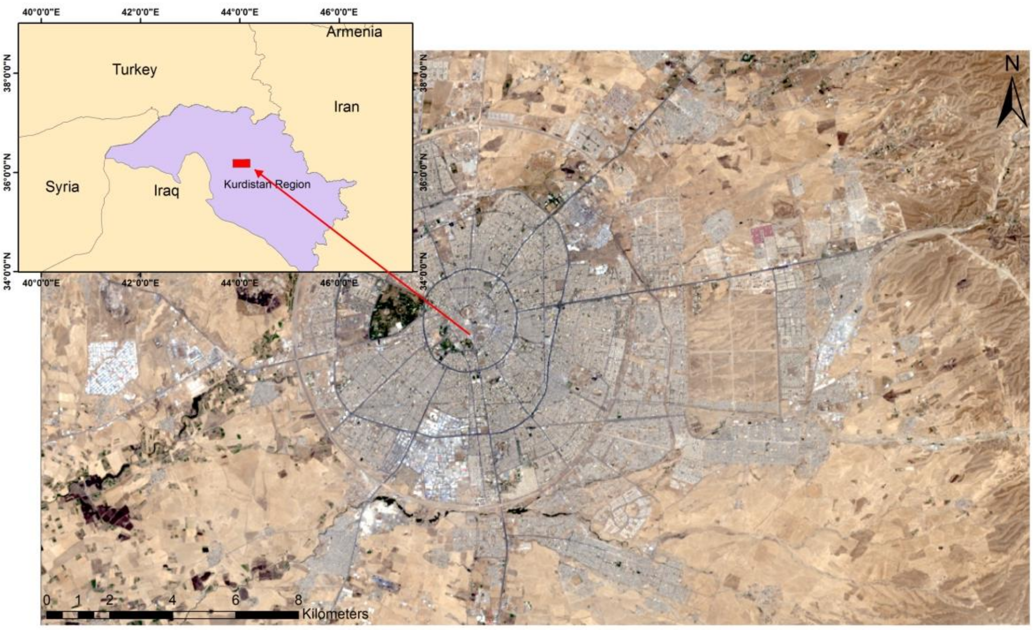

Fig. 1 Overview of Erbil Study area

presented by grasses and forests. The area is mainly characterised as an anticline/syncline system. The Tigris River is located in the southern part of the Erbil Governance. The Iraqi Kurdistan area is heavily employed for agricultural purposes in Iraq (Hameed, 2013) (Fig. 1).

In Erbil Governance approximately 41% and 59% are formed by arable and non-arable lands respectively (SOITM, 2013). The dominating proportion of non-irrigated agricultural crops (93%) is highly dependent on rainfall while the remaining 7% of crops are irrigated. Dominate soil types found in Erbil as well as the adjacent territories are clay and limestone. Their proportions are found to increase with depth. Both the upper and the bottom layers of the Erbil region soil are composed of brown clay. In addition to the indicated types of formations, soils of the city are presented by sand, plaster and gravel (Hameed, 2013).

Erbil City is located in a transition area characterised by Mediterranean and Arid climatic features. The climate is characterized by mild winters and warm/hot summers. An average rainfall range in Erbil area is 300-400 mm per annum with the highest rainfall levels during the period between October and April. The annual relative humidity in the Erbil area is approximately 35% and the monthly average air temperature ranges from 10 ºC to 25 ºC. The climate of the study area is typically dry in summer with little to no precipitation, while winters are wet (Hameed, 2013). In 2011, the Erbil municipality has a population of 884,299 people and a density of 6000 persons per km^2 and the population is rapidly expanding.

DATA AND METHODOLOGY

Data

MODIS Vegetation Indices

Vegetation indices such as NDVI and EVI are designed to provide consistent spatial and temporal comparisons of vegetation conditions and cover, allowing biomass productivity monitoring and quantifying changes in vegetation cover (Colditz et al., 2006; Mertes et al., 2015; Rizzi et al., 2006). The study uses a 16 day composite for each NDVI and EVI raster (MOD13Q1), captured by the MODIS-Terra sensor. Blue, red, and NIR reflectance bands, centered at 469 nm, 645 nm and 858 nm respectively, are used to determine the MODIS vegetation indices, with a spatial resolution of 250m (USGS, 2016). MODIS products are computed from atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols, and cloud shadows (USGS, 2016). The equations for NDVI and EVI are described below (Huete, et al., 2002).
The NDVI is determined as:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The EVI is determined as:

$$EVI = 2.5\,\frac{NIR - Red}{NIR + (6 * RED) - (7.5 * BLUE) + 1}$$

The purpose of EVI is to improve on a standard NDVI MODIS product. The benefits of EVI include; enhancement of vegetation signal and sensitivity in biomass abundant regions, reduction of soil and atmospheric effects and the reduction of the smoke impact, generated as the result of biomass combustion in tropical area (Xiao et al., 2009). Improving on NDVI, MODIS includes (EVI) that minimizes canopy background variations and maintains sensitivity over dense vegetation conditions (USGS, 2016). The EVI also uses the blue band to remove residual atmosphere contamination caused by smoke and sub-pixel thin clouds. The MODIS NDVI and EVI products are computed from atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols, and cloud shadows (USGS, 2016). MODIS (MOD13Q1) data was employed to create a time series of NDVI and EVI over the study area annually, between 2000 and 2015 to determine variations of vegetation extent.

MODIS Land Cover

The study uses MODIS Land Cover Type Yearly L3 Global 500m resolution (MCD12Q1), Land Cover Type 1 (IGBP) global vegetation classification scheme where selected among five global land cover classification systems. The MODIS land cover product (MCD12Q1) is classified into five land cover classes; Open Shrub land, Grassland, Cropland, Urban/Built-up area and Bare or spare vegetation. MODIS land cover is used to carry out change assessment and distribute NDVI and EVI to in land cover classes.

Climate Data

Average temperature, humidity and total rainfall and for March and December were collected from Erbil station and plotted over the 15 year period (2000-2015). Humidity data was collected at the altitude of 470 m. All climate data was sourced from the Kurdistan region government, Ministry of Agriculture and Water Resources (2016).

Methodology

The year of 2005 was chosen as a moderate year in terms of temperature and rainfall, to avoid the impact of climate extremes on the results. Where average of rainfall and temperatures were extracted for 75 years and the selected year was closer to moderation. Both NDVI and EVI was March the month of highest value, while the lowest levels of vegetation were identified in December (Fig. 2).

The project methodology was summarized in Figure 3. Data compilation and raster statistics were generated in ArcGIS 10.3. Statistical analysis and investigation of possible trends were carried in Microsoft Excel. Pre-processing of satellite data was required and was conducted in the study. Data pre-processing for included checking pixel reliability and vegetation index quality. Bad pixels are omitted from the analysis as they represent clouds, shadows from the clouds and cover the true value of the ground reflectance. Where the pixel representation must be more than 2/3 of the area, therefore the 2009 data for both March and December contain a very high portion of bad pixels. Several years of data captured in December (2000-2002, 2006-2009 and 2011) also contain very high portions of bad pixels (Table 1).

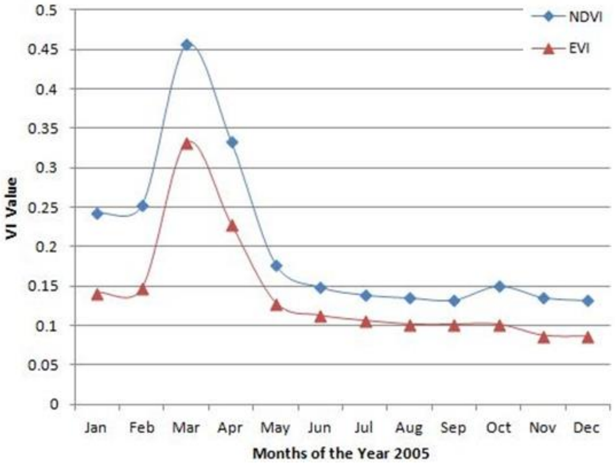

Fig. 2 Mean NDVI, EVI time series from months of the year 2005, showing minimum and maximum values in the study area

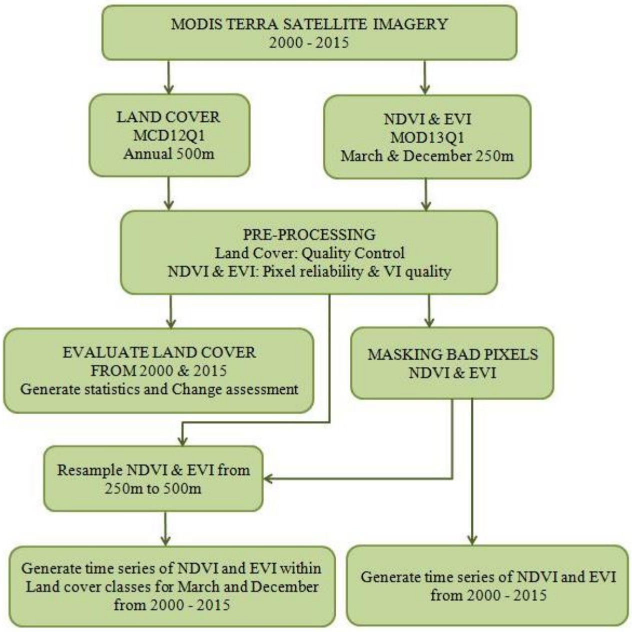

Fig. 3 Methodology summary of the project

Mean NDVI and EVI were generated to provide an average index over the complete study area, allowing the comparison between years to examine a temporal trend. Plots of monthly NDVI and EVI statistics (mean, minimum, maximum and standard deviation) are generated from 2000 to 2015, identifying temporal variations.

MODIS land covers (MCD12Q1) the quality control of the pixels was verified and all were excellent. Conducting detection of change assessment, by comparing the areas of five land covers and generate time series of NDVI and EVI within land cover classes from 2000 to 2015.

Table 1 Summary of QA layers good pixel representation for each year

	March		December
Year	**Pixel representation (%)**	**Year**	**Pixel representation (%)**
2000	100	2000	40.7
2001	100	2001	66.55
2002	100	2002	49.93
2003	100	2003	81.03
2004	100	2004	97.43
2005	100	2005	96.68
2006	100	2006	71.32
2007	100	2007	47.9
2008	100	2008	65.66
2009	56.81	2009	56.83
2010	98	2010	99.47
2011	100	2011	68.02
2012	91.33	2012	87.61
2013	100	2013	90.8
2014	99.88	2014	99.98
2015	100	2015	96.78
Mean	96.63	Mean	76.04

RESULTS

This section presents time series scatter plots of mean NDVI and EVI values and summary statistics including standard deviation, minimum and maximum.

MODIS NDVI and EVI

An obvious difference is apparent between March and December of mean NDVI and EVI over the 15 year period in the same area, presented in Figures 4 and 5. March had significantly higher means and greater variability of VI levels compared to December. December showed some variability at maximum VI levels however the mean was fairly constant with a small peak in 2014. The differences between March and December could be based on seasonal growth variations. After the wet season, March generally has much greater NDVI and EVI values, expect for 2008. In December 2008 NDVI and EVI values were very similar to the averages in March. Both VI in March 2010 showed highest level due heavy rains this month. However both months for NDVI and EVI showed a gradual increasing trend from 2000 to 2015 (Fig. 4 and 5). Important to note is that both NDVI and EVI time series plots appear to have similar patterns.

NDVI and EVI images for March 2002 (baseline) and March 2015 (final year) are compared in Figure 6 to visualize the spatiotemporal variation of vegetation. March had the highest vegetation growth, and will best represent differences in true vegetation coverage extent. It is evident that the spatial distribution of urban areas and/or bare or sparely vegetated areas surrounding Erbil has expanded over the past 15 years and consequently vegetation surrounding the urban centre has been replaced by urban growth. However it appears that agricultural areas in rural region have expanded possibly to support population growth. The NDVI maps appear to have greater areas of high vegetation health compared to the EVI maps (Fig. 6).

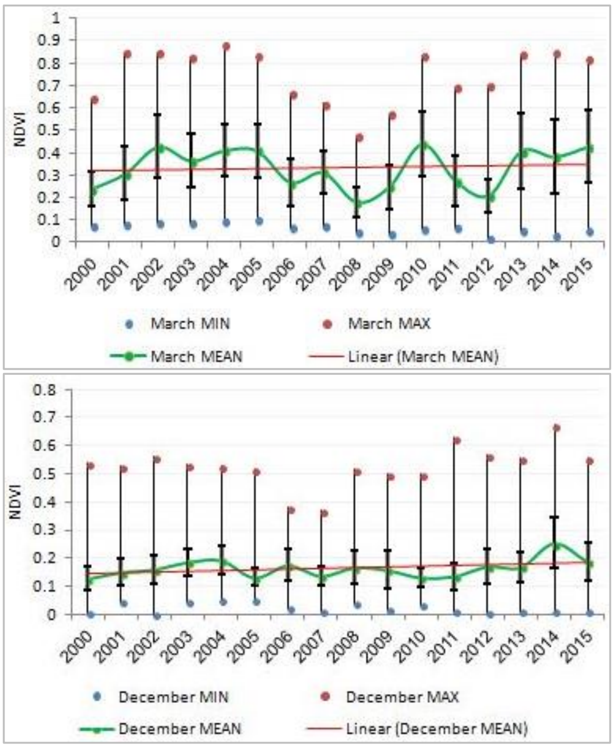

Fig. 4 NDVI Time series from 2000 – 2015 in the whole area, comparing mean, minimum, maximum and standard deviation values for March and December in the study area

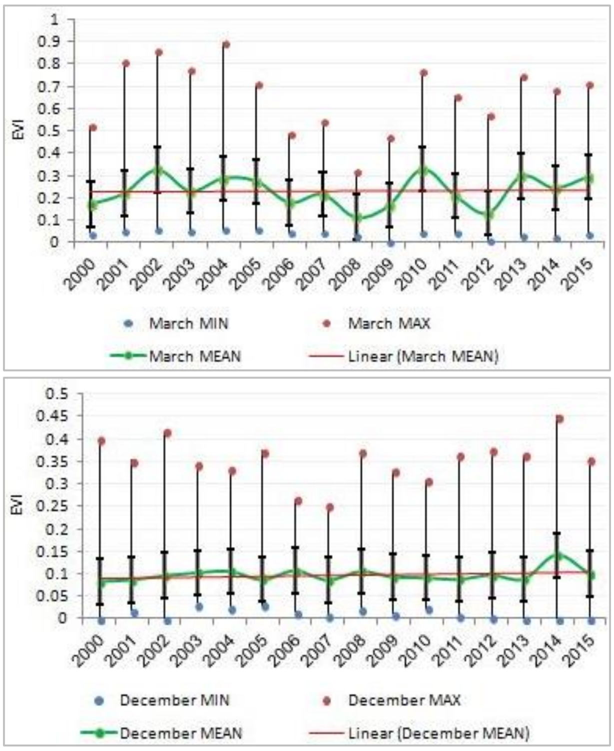

Fig. 5 EVI Time series from 2000 – 2015 in the whole area, comparing mean, minimum and maximum and standard deviation for March and December in the study area

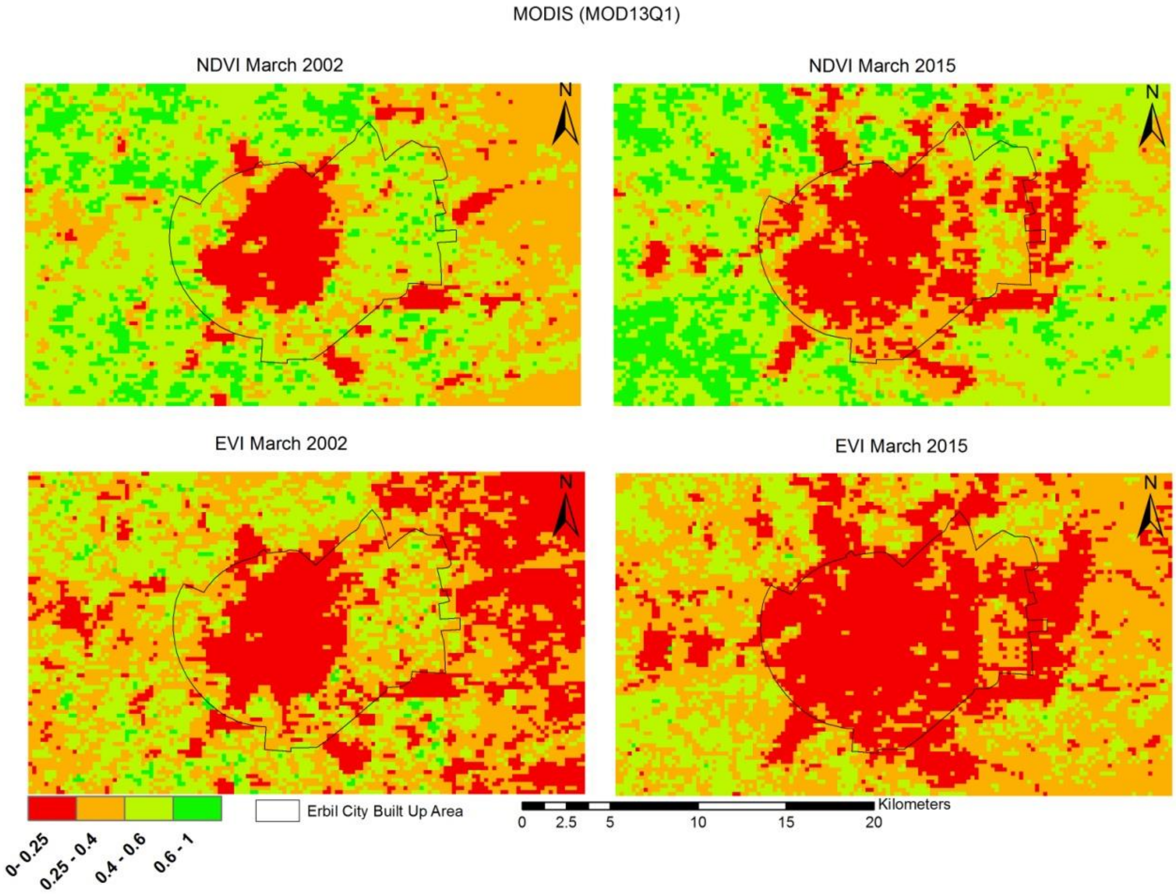

Fig. 6 NDVI and EVI maps for March 2002 and 2015

Interesting to note, there is a decline in urban green spaces such from 2002 to 2015 in both NDVI and EVI images. The green space may still be present, but in poor health or have reduced in size.

The NDVI and EVI values captured in March had a greater variability, compared to data captured in December. Annual MODIS data captured in March was used to calculate land cover statistics for time series for both indices (Fig. 7 and 8). The majority of the years contained VI values with little variation, except for both VI in 2002 2010 and 2014 (Fig. 7 and 8). This may be explained by abrupt climatic changes resulting in vegetation growth or decline. The cropland class had the highest NDVI values over any other class during the 15 year period (Fig. 7), which is expected as healthy green homogeneity crops will exhibit a higher NDVI value compared to open shrub and grassland ecosystems that contain various plant species with varying foliage colours and types. Bare/sparsely vegetated and urban areas displayed the lowest mean NDVI vales over the study area over the 15 year period.

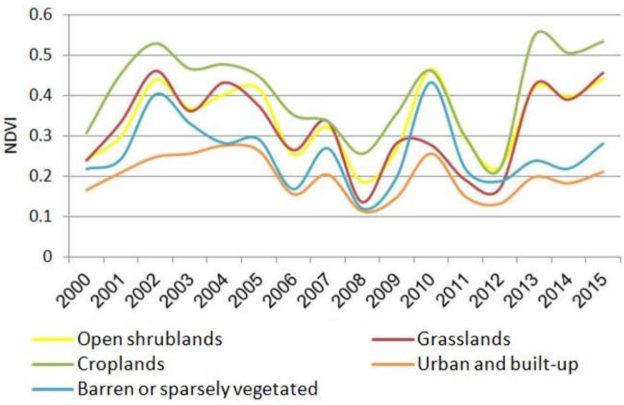

Fig. 7 Mean NDVI values from March 2000–2015, comparing 5 land cover types

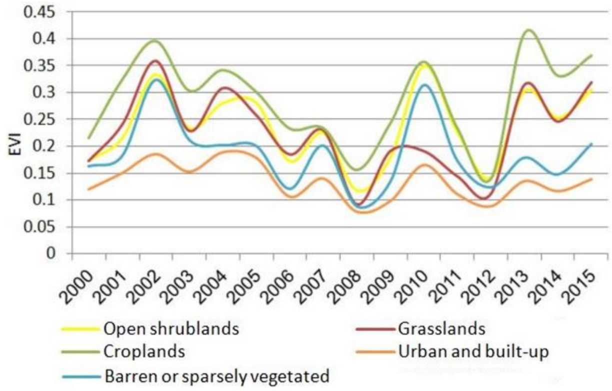

Fig. 8 Mean EVI values from March 2000 – 2015, comparing 5 land cover types

The EVI time series presents as well similar trend, as cropland appear to generally have a greater biomass over grasslands and open shrub land over the 15 year period, (Fig. 7). Cropland EVI exceeds grassland possibly from additional crop irrigation for those years. As expected EVI in urban areas remains relatively low over the study period, however EVI in bare/sparsely vegetated classes seems to spike in 2002 and 2010 (Fig. 8). The spikes may be explained by an increase in sparse vegetation species and opportunistic species such as weeds. Based on Figures 7 and 8 it can be suggested that NDVI is more sensitive than EVI for fluctuations in vegetation health and biomass.

MODIS Land Cover

Figure 9 compares MODIS land cover classification between 2000 and 2015. The foremost visual difference is the reduction of bare or sparsely vegetated land and increase in grasslands. The spatial distribution of the urban area has remained relatively similar at this resolution. Therefore, we verified through Landsat images 30m resolution, where urban and Built-up area 58% increased over

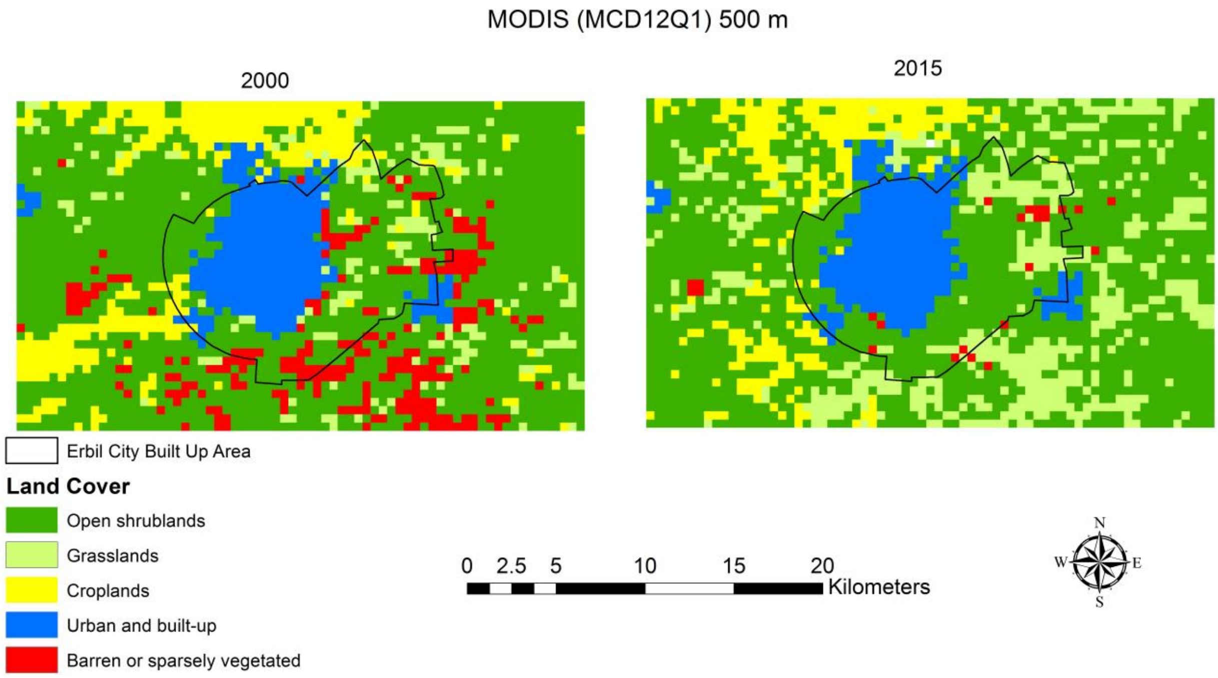

Fig. 9 Comparison of MODIS land cover between 2000 and 2015

the time period (Hussein, 2017). The area of land cover types and percentage differences comparing the baseline year 2000, to the final year 2015, are highlighted in Table 2. Between the 15 years there has been a significant decrease of bare or sparsely vegetated land (90%) and a slight decrease of cropland (18%) and open shrub land (4%). However there has been a 67% increase of grasslands. Based on these observations, we can assume the majority of bare or sparsely vegetated land has transitioned into grassland, outside of the urban center between 2000 and 2015.

Table 2 Land cover area and percentage differences comparing 2000 to 2015

	2000	***2015***		
Land Cover	***Area (ha)***	***Area (ha)***	***Difference (ha)***	***Change within Cover type (%)***
Open Shrublands	42825	41050	1775	-4
Grasslands	4375	13150	-8775	+67
Croplands	8275	6775	1500	-18
Urban and Built-up Area	7425	7425	0	No change
Barren or Sparsely Vegetated	6100	600	5500	-90
Total	**69000**	**69000**		

Climate

Annual rainfall, average temperature (Fig. 10), and average humidity (Fig. 11) and covering the 16-year period are presented below. Rainfall was considerably high in 2003 and 2006, followed by low rainfall years in 2004, 2010, and 2007 (Fig. 10). After 2007 total rainfall has remained more constant with less variation between years, with a positive increasing trend towards 2015.

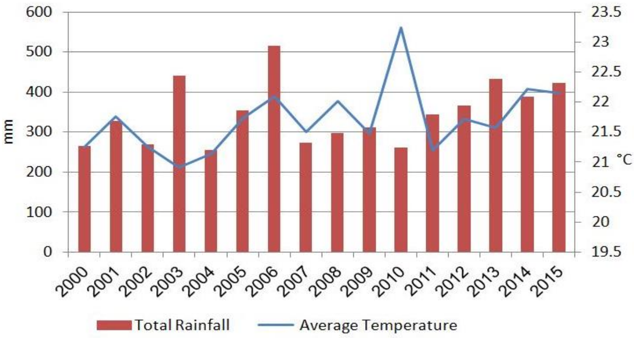

Fig. 10 Total annual rainfall and average temperature time series from 2000 – 2015

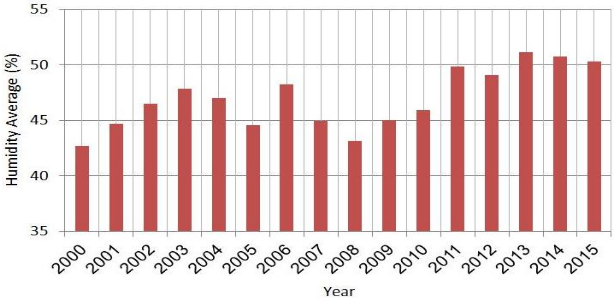

Fig. 11 Annual mean humidity time series from 2000 – 2015

Humidity shares a similar pattern to rainfall, with high averages in 2003 and 2006, followed by lows and then a gradual increasing trend towards 2015 (Fig. 11). Interesting to note, average temperature for 2003 was the lowest over the 16 year period, while in 2006 the temperature was relatively high for that period (Fig. 10). In 2010 average temperature spiked at 23°*C*, the highest average temperature over the 16 years. By comparison total rainfall was very low in 2010 with average humidity. Average rainfall, humidity and temperature all appear to have generally increased between 2000 and 2015 with various positive and navigate fluctuations in-between.

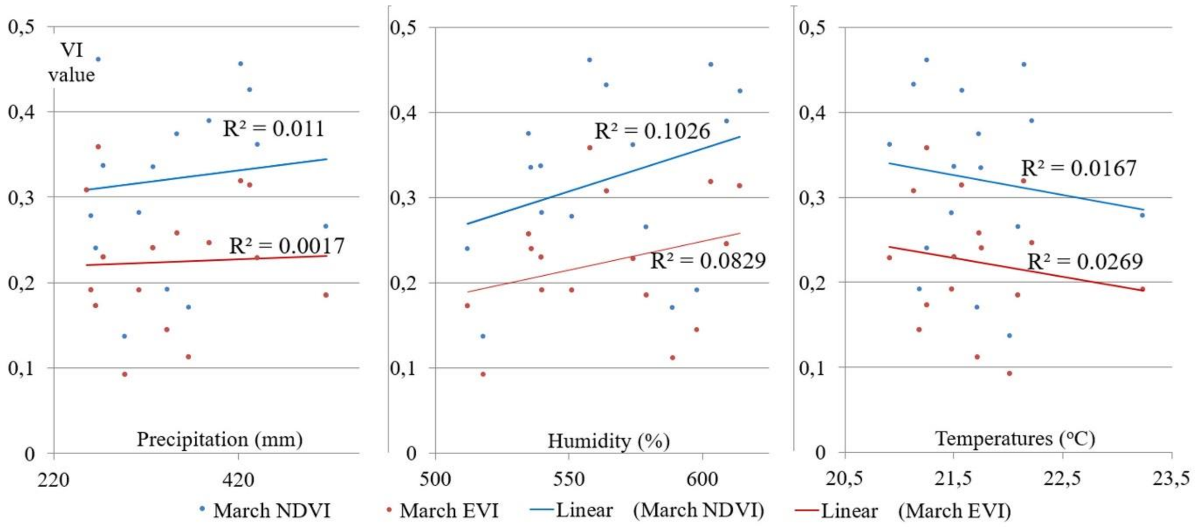

Fig. 12 Time series (2000 – 2015) correlation analysis between rainfall, humidity, temperature and vegetation indices (NDVI and EVI) within grasslands for March

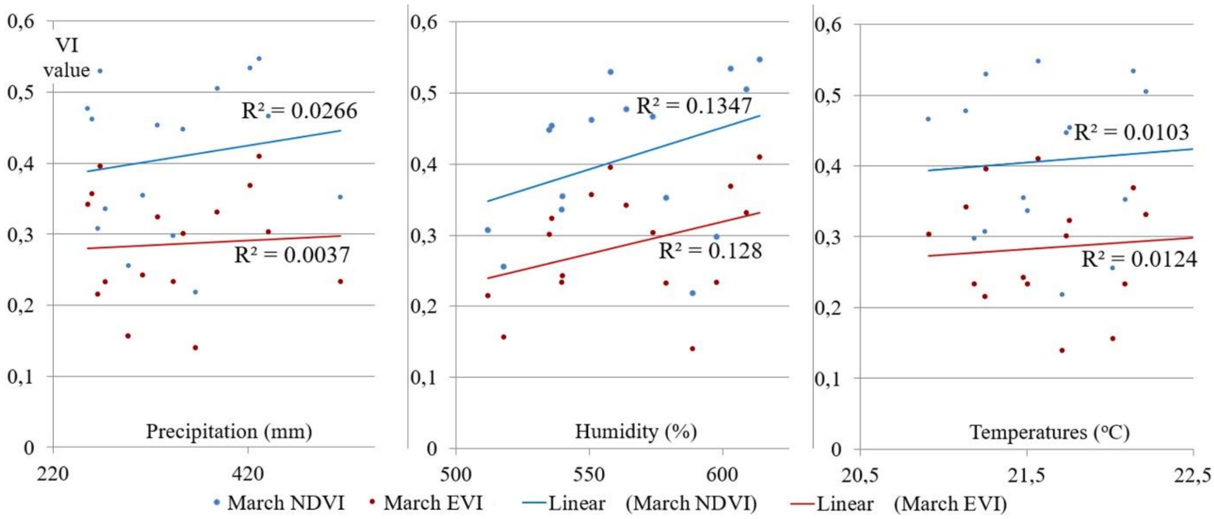

Fig. 13 Time series (2000 – 2015) correlation analysis between rainfall, humidity, temperature and vegetation indices (NDVI and EVI) within croplands for March

Climate variables were compared with NDVI and EVI by correlation analysis (Fig. 12-13). Rainfall, humidity and temperature averages for March were compared to mean NDVI and EVI levels within grasslands and croplands captured in March. There was no strong evidence of correlation between NDVI or EVI and any of the climate variables. All comparisons between climate and NDVI or EVI were not significant.

DISCUSSION

Remote sensing of urban sprawl and green space provides information on the spatial and temporal patterns of human growth that are useful for understanding differences in socioeconomic and political factors as well as environmental and climatic impacts (Mertes et al., 2015). Based on NDVI and EVI MODIS data (Fig. 6) imagery the spatial distribution of urban areas in Erbil and the bare around it has expanded. Consequently the vegetation area has been cleared and replaced over the past 15 years by urban growth.

However it appears that agricultural or grassland areas in rural regions have expanded slightly, to possibly support population growth. Based on our observations, we can assume most of bare or sparsely vegetated land has transitioned into grassland, outside of the urban centre. Urbanization can substantially alter the abundance and distribution of vegetation (Gregg et al., 2003). However this statement is unclear for the city and surrounds of Erbil based on the spatial resolution (250m, 500m) of the MODIS data. A finer imagery resolution of 30m or less is required.

Mapping within an urban landscape is not an easy task, due to the small footprints of features such as parks and trees, mixed between clusters of buildings and roads. Urban areas are typically heterogeneous in both material composition and configuration and with new development they are often highly variable between locations (Mertes et al., 2015). Vegetation indices are useful for extracting green space features from complex urban areas. The NDVI and EVI MODIS imagery with its course resolution was still able to successfully identify spatial and temporal patterns of human growth in the City of Erbil. Additional research is recommended utilizing imagery of higher resolution such as Landsat with a 30m spectral resolution. To determine the distribution of green space within the urban area of Erbil, Worldview 2 imagery is recommended with
2m spatial resolution.

The urban expansion pattern observed in Erbil is highly dependent on the Tigris River. The city is represented by a matrix of interconnected patches that vary from non vegetated areas such as impervious surfaces to areas of high plant diversity (SOITM, 2013). The combination of vegetated land patches lead to the formation of elevated plant diversity in Erbil (Neil and Wu, 2006). Agricultural activities such as clearing, burning and herbicides uses have impacted plant community distribution outside of the urban centers. However within the urban landscape the observed vegetation patterns or urban green spaces (UGS) are a direct consequence of reconstruction activities, including alteration of urban landscape as well as city gardens and forests. The green areas in Erbil are managed by governments, institutions and individuals. It is expected that the outlined bodies directly control abundance and biodiversity of green spaces within the city. Erbil is one of the oldest cities in the world, therefore it could be expected that the cities preservation activities should be aimed towards green space and plant diversity conversation, however this is not the case (UNESCO, 2016).

Urban Green Spaces are essential constituents of the urban structure that enhance resident's quality of life and behaviour (M'Ikiugu et al., 2012). UGSs contribute to the sustainable development of urban ecosystems and provide a range of ecological and social benefits including; biodiversity and historic landscape feature conservation, regulate local microclimate, protection of air quality, noise absorption and water resources protection. UGS also maintain and improve human well-being by contributing to recreation and aesthetic activities (M'Ikiugu et al, 2012).

CONCLUSION

Spatiotemporal variations of vegetation indices (EVI and NDVI) between 2000 and 2015 was successfully observed using MODIS data. It was evident that the spatial distribution of bare or sparely vegetated areas surrounding Erbil has expanded over the past 15 years, and consequently vegetation surrounding the urban centre has been replaced by urban growth including grassland or green space. It is suggested the majority of bare or sparsely vegetated land has transitioned into grassland, outside of the urban center between 2000 and 2015.

There was no evidence of correlation between any of the climate variables to NDVI or EVI. March 2010 was a dry, warm period, which spiked VI averages above normal, mainly because of sparsely vegetated or open shrub lands. Opportunistic weed and dry grass species that thrive in these conditions may explain the spike in VI. Overall vegetation indices showed a gradual increasing trend from 2000 to 2015, but vegetation extent decreased based on the land cover information.

Human alteration of the environment has caused a spatiotemporal transition from native plant species to managed monocultures for agricultural purposes or urban development. Considering vegetation distribution in the surroundings of Erbil city it can be stated that according to the collected MODIS data the Iraqi Kurdistan region manifested high levels of vegetation regardless of the period of the year. It is expected that vegetation patterns in this region are highly manipulated and dependent on anthropogenic activity because this region plays an important role in the agricultural infrastructure of the country.

References

Bonan, G. 2002. Ecological Climatology. Cambridge University Press, p. 690.

Camberlin, P., Martiny, N., Philippon, N., Richard, Y. 2007. Determinants of the interannual relationships between remote sensed photosynthetic activity and rainfall in tropical Africa. *Remote Sensing of Environment* 106 (2), 199–216. DOI: 10.1016/j.rse.2006.08.009

Colditz, R., Conrad, C., Wehrmann, T., Schmidt, M., Dech, S. 2006. Generation and assessment of MODIS time series using quality information. *IEEE International Geoscience and Remote Sensing* Symposium, IGARSS, p.6. DOI: 10.1109/igarss.2006.200

Gregg, J., Jones, C., Dawson, T. 2003. Urbanisation effects on tree growth in the vicinity of New York City. *Nature* 424, 183–187. DOI: 10.1038/nature01728

Hameed, H. 2013. Water Harvesting In Erbil Governorate, Kurdistan Region, Iraq, Lund University.

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., Ferreira, L.G. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83 (1-2), 195–213. DOI: 10.1016/s0034-4257(02)00096-2

Hussein, S. 2017. The geographical evolution of urban greenness in the city of Erbil based on Landsat imagery. Regional Committee of the Hungarian Academy of Sciences, Pécs, 232–239.

Imhoff, M., Zhang, P., Wolfe, R., Bounoua, L. 2010. Remote sensing of the urban heat island effect across biomass in the continental USA. *Remote Sensing of Environment*, 114 (3), 504–513. DOI: 10.1016/j.rse.2009.10.008

Kurdistan Region Government, 2016. Ministry of agriculture and water resources, Iraq.

Li, Z., Li, X., Wei, D., Xu, X., Wang, H. 2010. An assessment of correlation on MODIS-NDVI and EVI with natural vegetation coverage in Northern Hebei Province, China. *Procedia Environmental Sciences* 2, 964–969. DOI: 10.1016/j.proenv.2010.10.108

Los, S., Weedon, G.P., North, P.R.J, Kaduk, J.D., Taylor, C.M., Cox, P.M. 2006. An observation-based estimate of the strength of rainfall-vegetation interactions in the Sahel. *Geophysical Research Letters* 33(16), DOI: 10.1029/2006GL027065

Lunetta, R.S., Knight, J.F., Ediriwickrema, J., Lyon, J.G., Worthy, L.D. 2006. Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment* 105(2), 142–154. DOI: 10.1016/j.rse.2006.06.018

M'Ikiugu, M. M., Kinoshita, I., Tashiro, Y. 2012. Urban Green Space Analysis and Identification of its Potential Expansion Areas. *Procedia - Social and Behavioral Sciences* 35, 449–458. 10.1016/j.sbspro.2012.02.110

Mertes, C., Schneider, A., Sulla-Menashe, D., Tatem, A.J., Tan, B. 2015. Detecting change in urban areas at continental scales with MODIS data. *Remote Sensing of Environment* 158(1), 331–347. DOI: 10.1016/j.rse.2014.09.023

Myneni, R.B., Yang, W., Nemani, R.R., Huete, A.R., Dickinson, R.E. et al. 2007. Large seasonal changes in leaf area of amazon rainforests. *PNAS* 104(12), 4820–4823. DOI: 10.1073/pnas.0611338104

Neil, K., Wu, J. 2006. Effects of urbanisation on plant flowering phenology. *Urban Ecosystem* 9(3), 243–257. DOI: 10.1007/s11252-006-9354-2

Nicholson, S., Davenport, M, Malo, A. 1990. A comparison of the vegetation response to rainfall in the Sahel and East Africa, using normalized difference vegetation index from NOAA AVHRR. *Climatic Change* 17(2), 209–241. DOI: 10.1007/bf00138369

Rizzi, R., Rudorff, B., Shimabukuro Y., Doraiswami, P. 2006. Assessment of MODIS LAI retrievals over soybean crop in southern Brazil. *International Journal of Remote Sensing* 27(19), 4091–4100. DOI: 10.1080/01431160600851850

Schwarts, M., 2013. Phenology: An Integrative Environmental Science. Springer, London, p.602.

SOITM, 2013. Erbil City. Turkmen Human Rights: Research Foundation, New York.

Suepa, T., Jiaguo, Q., Lawawirojwong, S., Messina, J. 2016. Understanding spatio-temporal variation of vegetation phenology and rainfall seasonality in the monsoon Southeast Asia. *Environmental Research* 147, 621–629. DOI: 10.1016/j.envres.2016.02.005

Word Bank, 2015. Data Catalog. http://data.worldbank.org

Tucker, C, Slayback, D.A., Pinzon, J.E., Los, S.O., Myneni, R.B., Taylor, M.G. 2001. Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999. *International Journal of Biometeorology* 11(2), 184–190. DOI: 10.1007/s00484-001-0109-8

UNESCO, 2016. UNESCO World Heritage Centre. http://en.unesco.org/

United Nations Development Program, 2016. United Nations Development Program. http://www.undp.org/

United Nations, 2014. World urbanization prospects. New York: United Nations, p.32.

USGS, 2016. Vegetation Indices 16-Day L3 Global 250m. https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13q1

Xiao, X., Zhang, J., Yan, H., Wu, W., Biradar, C. 2009. Land surface phenology: Convergence of satellite and CO2 eddy flux observation. In.: Normeets A. (ed.) Phenology of Ecosystem processes. Springer Sciences+Business Media, New York, 247–270. DOI: 10.1007/978-1-4419-0026-5_11

Yuan, F., Bauer, M. 2007. Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment* 106(3), 375–386. DOI: 10.1016/j.rse.2006.09.003

Zhang, X., Friedl, M., Schaaf, C. 2006. Global vegetation phenology from moderate resolution imaging Spectroradiometer (MODIS): evaluation of global patterns and composition with in situ measurements. *Journal of Geophysical Research 111*(G04017), 1–14. DOI: 10.1016/j.rse.2006.09.003

Zhang, X., Friedl, M., Schaaf, C., Strahler, A. 2005. Monitoring the response of the vegetation phenology to precipitation in Africa by coupling MODIS and TRMM instruments. *Journal of Geophysical Research* 110(D12), 1–14. DOI: 10.1029/2004jd005263